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Efficient reversible data hiding algorithm based on gradient-based edge direction prediction

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ABSTRACT

In this paper, we present an efficient RDH algorithm based on a new gradient-based edge direction prediction (GEDP) scheme. Since the proposed GEDP scheme can generate more accurate prediction results, the prediction errors tend to form a sharper Laplacian distribution. Therefore, the proposed algorithm can guarantee larger embedding capacity and produce better quality of marked images. The determination of appropriate thresholds is also a critical issue for a RDH algorithm, so we design a new systematic way to tackle this problem. In addition, a modified embedding order determination strategy is presented to reduce the distortion of a marked image. Based on typical test images, experimental results demonstrate the superior properties of the proposed algorithm in terms of embedding capacity and marked image quality.

1. Introduction

Reversible data hiding (RDH) techniques can embed hidden data in a host image as well as allow the recovery of the original image without any distortion after extracting the hidden data (Honsinger et al., 2001). They are widely applied to the field of sensitive images, such as military, medical, and art work images, since the complete reconstruction of original images is required. For the RDH issue, the two most important measures are embedding capacity and quality degradation of a marked image. Therefore, a successful RDH algorithm not only can achieve large embedding capacity, but also minimize the distortion introduced by the embedding process.

Previously, many RDH methods were developed. Vleeschouwer et al. (2003) presented an RDH algorithm for media asset management based on circular interpretation of bijective transformations. Tian (2003) presented an RDH algorithm based on an integer Haar wavelet transform (Mallat, 1999) and difference expansion, and Alattar (2004) developed an RHD algorithm using the difference expansion on vectors formed by successive pixels. Kamstra and Heijmans' algorithm (Kamstra and Heijmans, 2005) fixed the image distortion problem that is existing in Tian's algorithm (Tian, 2003). Tsai et al. (2005) proposed an RDH algorithm for binary images. Ni et al. (2006) and Chang et al. (2006) developed RDH algorithms based on the peak-valley pairs of an image histogram and the outcome of side match vector quantization, respectively. Chang and Lu (2006) presented an RHD algorithm, which uses the indices of the codewords to embed hidden data, for side match vector quantization-compressed images. For joint photographic experts group (JPEG) images, Chang et al.'s RHD algorithm (Chang et al., 2007) embedded the hiding data in the medium-frequency part of the quantized discrete cosine transformation (DCT) coefficients. For vector quantization-compressed images, Chang and Lin (2007) presented an RHD algorithm based on a de-clustering strategy. Sachnev et al. (2007) enhanced the embedding capacity of Alattar's algorithm (Alattar, 2004) by exploiting quad pixels to embed hidden data and simplifying the location map. Using LOCO-I predictor (Weinberger et al., 1996), Thodi and Rodriguez (2007) presented a high capacity RDH algorithm based on the concept of prediction error expansion. For block truncation coding-compressed color images, Chang et al. (2008) developed an RHD algorithm utilizing the common bitmap to embed hidden data. Kim et al. (2008) presented a novel difference expansion transform to improve the capacity and quality performance of Kamstra and Heijmans'

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algorithm (Kamstra and Heijmans, 2005). Lin et al. (2008) presented a multilevel RHD algorithm that modifies the difference image histogram and uses the peak value to embed hidden data. Chang et al. (2009) developed an RHD algorithm based on the joint neighboring coding technique for images compressed by vector quantization. Tai et al. (2009) presented an improved RHD algorithm to solve the problem of communicating multiple peak points to recipients in Lin *et al.*'s algorithm (Lin et al., 2008). Without using the threshold, Lin et al. (2010) enhanced the quality performance of Alattar's algorithm (Alattar, 2004) by embedding hidden data in the smooth areas determined through the proposed quad of quads structure. Sachnev et al. (2009) presented an efficient RDH algorithm by combining the sorting and error prediction concepts. For Chinese character data, Wang et al. (2009) developed an RDH algorithm using left-right and up-down Chinese character representation. Based on the interpolation technique, Luo et al.'s RHD algorithm (Luo et al., 2010) used the differences between interpolation values and actual pixel values to embed hidden data. Hwang et al. (2010) proposed a histogram shifting-based RHD algorithm exploiting the diamond prediction scheme and sorting strategy. Based on the spectral-spatial correlation in the color difference domain (Chung et al., 2008; Pei and Tam, 2003), Yang et al. (2012) developed the first RHD algorithm designed specifically for color filter array mosaic images.

After examining the previously developed RDH algorithms using the prediction errors and difference expansion, we know that the embedding capacity and marked image quality depend on the prediction scheme employed in the RDH algorithm. In this paper, we develop an improved RDH algorithm based on a new gradient-based edge direction prediction (GEDP) scheme. We try to model the prediction errors as a sharper Laplacian distribution. Therefore, the proposed algorithm can achieve larger embedding capacity and produce better quality of marked images. Since the determination of appropriate thresholds is also a critical issue for an RDH algorithm, we design a new systematic way to tackle this problem. In addition, we propose a modified version of the embedding order strategy which is better than one proposed by Sachnev et al. (2009) to improve the outcome. Eighteen images are used to evaluate the related performance and the results indicate that the proposed RDH algorithm is superior to four existing RHD algorithms, namely Tai et al.'s algorithm (Tai et al., 2009), Thodi and Rodriguez's algorithm (Thodi and Rodriguez, 2007), Luo et al.'s algorithm (Luo et al., 2010), and Sachnev et al.'s algorithm (Sachnev et al., 2009). We compare the proposed RHD algorithm with the above four RHD algorithms due to the following two reasons. First, like the proposed algorithm, the four compared algorithms are based on the concepts of prediction error expansion and histogram modification. Second, they are regarded as the state-of-the-art RHD algorithms. Note that since all the RDH algorithms mentioned above are discussed in an attack-free environment, out work follows the same environment assumption.

The three main contributions of this work are as follows. First, we develop a new GEDP scheme to reduce the prediction errors, and it is the most crucial factor that influences the performance of an RDH algorithm. Second, we design a new systematic way to determine the appropriate thresholds which can provide enough usable capacity to embed hidden data and some overheads as well as generate the best quality of a marked image. Finally, a modified embedding order determination strategy is proposed to reduce the distortion of a marked image.

The rest of this paper is organized as follows. In Section 2, a brief review to the four state-of-the-art prediction error-based RHD algorithms is given. In Section 3, we present the proposed GEDP scheme and discuss the Laplacian distribution of the prediction errors. In Section 4, we describe the proposed RDH algorithm. Section 5 reports the experimental results to demonstrate the advantages of our RDH algorithm. Finally, concluding remarks are drawn in Section 6.

2. Previous works

Before presenting the proposed GEDP scheme and RHD algorithm, in this section, we briefly review the four state-of-the-art prediction error-based RHD algorithms proposed by Tai et al. (2009), Thodi and Rodriguez (2007), Luo et al. (2010), and Sachnev et al. (2009), respectively. The four RHD algorithms are based on the concepts of prediction error expansion and histogram modification. They utilize prediction schemes to predict the pixel values and embed hidden data in the image by modifying the corresponding prediction errors.

Tai et al.'s RHD algorithm (Tai et al., 2009) scans an image by an inverse s-order and uses the last scanned pixel value as the prediction value of the current pixel. After constructing the histogram formed by the prediction errors, the hidden data are embedded by the histogram modification. Without using the location map, Tai et al.'s algorithm directly contracts the histogram from both sides to ensure that the embedding hidden data does not cause the overflow and underflow problems. Their algorithm also utilizes a binary tree structure to resolve the problem of communicating multiple peak points to recipients, which is the major drawback in Lin et al.'s algorithm (Lin et al., 2008).

Thodi and Rodriguez (2007) first utilizes the LOCO-I predictor (Weinberger et al., 1996), which is based on the mutual relation in the neighborhood of a pixel, to predict the value of each pixel. Then, they embed the hidden data in an image by using the combination of the prediction error expansion and the histogram shifting scheme. Furthermore, instead of using the location map, a two-pass testing method with a flag bit stream is presented to resolve the overflow or underflow problem, leading to enhancing the embedding capacity.

In Luo et al.'s RHD algorithm (Luo et al., 2010), pixel values are predicted by using the interpolation scheme. Then, the pixels with prediction errors falling into the two highest peaks of the histogram are exploited to embed hidden data by using the additive error expansion. To prevent the overflow or underflow problem, Luo et al.'s RHD algorithm only uses the pixels whose values are within the range of 1 through 254 to embed the hidden data, and it utilizes a boundary map to resolve ambiguous problem when embedding a hidden bit in the pixel with value 1 or 254.

Sachnev et al.'s algorithm (Sachnev et al., 2009) predicts pixel values by averaging the gray values of the four neighboring pixels in a rhombus shape. The hidden data are embedded in the pixels whose corresponding prediction errors are within the range of the two thresholds, T_n and T_p, by using the difference expansion. Furthermore, in order to enhance the marked image quality performance, the shifting scheme by Thodi and Rodriguez (2007) is utilized and the embedding order is determined by a sorting strategy based on the local variances calculated by the differences between neighboring pixel pairs. According to our experiments, Sachnev et al.'s algorithm can embed more data with less distortion when compared with existing RDH algorithms.

Since the embedding capacity and marked image quality of the above prediction error-based RDH algorithms greatly depend on the employed prediction scheme, we can enhance the embedding and quality performance of an RHD algorithm by improving the prediction accuracy. Therefore, in what follows, we first present a more accurate GEDP scheme to predict the pixel values, and then based on the GEDP scheme, the proposed RDH algorithm with larger embedding capacity and better quality of marked images is developed.